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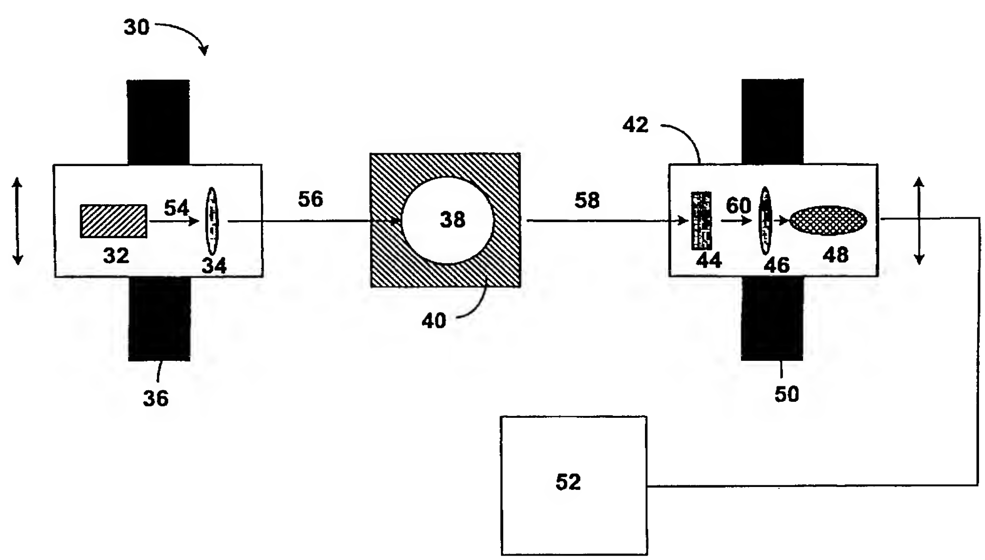

(57) Abstract: A method for automating measurement of an optical property of a sample includes selecting a measurement aperture around a reference point on the sample (38), generating a set of grid nodes that fall within the measurement aperture (68), calculating the radial distance of each node with respect to a reference point within the measurement aperture, and calculating the angular position of each node with respect to the vertical. The method also includes moving a light source (32) and a light detector along the vertical and rotating the sample to measurement positions in which the light source and the light detector are aligned with one of the nodes in the measurement aperture, and measuring the optical property at the measurement position by energizing the light source and interrogating the detector. The calculated radial distances and angular positions are used to control positioning of the light source and the light detector and rotation of the sample.

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AUTOMATED SYSTEM FOR MEASUREMENT OF AN OPTICAL PROPERTY

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of priority of U.S. Application Serial No. 09/458,561, filed December 9, 1999, entitled Automated System For Measurement Of An Optical Property, of Richard S. Priestley and U.S. Provisional Application Serial No. 60/204,405, filed May 16, 2000, entitled Automated System For Measurement Of An Optical Property, of Richard S. Priestley, which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Technical Field

The invention relates generally to systems for measuring birefringence or other optical property, e.g., transmission, of a sample of material.

2. Background Art

Birefringence, or double refraction, is a phenomenon that occurs in materials characterized by two indices of refraction. Typically, birefringent materials are optically anisotropic substances, e.g., calcite and quartz, although some isotropic materials such as glass and plastic become birefringent when subjected to stress. When a beam of light enters a birefringent material, the beam splits into two polarized rays each traveling at a different velocity, corresponding to a different index of refraction. One ray, called an ordinary ray, is characterized by an index of refraction that is the same in all directions. The second ray, called an extraordinary ray, travels with different speeds in different directions and hence is characterized by an index of refraction that varies with the direction of propagation. If the light entering the birefringent material is unpolarized or linearly polarized, the ordinary and extraordinary rays will have the same velocity along one direction, called the optic axis. The ordinary and extraordinary rays recombine upon exiting the material.

Birefringent materials can change the polarization state of a light passing through them. Therefore, the ability to accurately determine the birefringence of a

sample is important, especially in high performance optics, e.g., ophthalmic lenses, laser optics, and optical fibers, where a change in the polarization state of light can cause dramatic changes in optical performance. When linearly polarized light passes through a birefringent sample, the sample rotates the direction of polarization through some angle. By measuring this angle of rotation, the birefringence of the sample, i.e., the difference between the highest and lowest indices of refraction of the sample, can be determined. Typically, the sample is placed between two crossed linear polarizers. The birefringence at a given point about the cross section of the sample is then determined by measuring the angular position, with respect to the first linear polarizer, at which the light emerging from the sample is extinguished as it passes through the second linear polarizer.

Various other methods are known for determining birefringence. One example of a known method is disclosed in U.S. Patent 5,257,092 issued to Noguchi *et al.* As shown in FIG. 1, an optical source unit **2** emits a linearly polarized light beam, which passes through a quarter-wave plate **4.** The quarter-wave plate **4** converts the beam emitted by the optical source **2** to circularly polarized light, which then passes through the birefringent sample **6**, where the light emerges elliptically polarized. This emergent light then passes through a second quarter-wave plate **8** which converts the light to near-linear polarized light. The light then passes through a rotatable analyzer **10**. Birefringence is determined by measuring the angle of the analyzer **10** with respect to the source **2** at which light is extinguished. The method disclosed by the Noguchi *et al.* '092 patent uses circularly polarized light rather than linearly polarized light because, in the samples used, birefringence had to be measured in all directions. If linearly polarized light is used, there inherently will be a direction in which no birefringence occurs, i.e., the optic axis.

Another example of a method for measuring birefringence is disclosed in U.S. Patent 5,587,793 issued to Nakai *et al.* As illustrated in FIG 2, a sample **12** is placed between a circular polarizer **14** and a circular analyzer **16** and arranged in an optical path between a light source **18** and an optical receiver **20**. The circular polarizer **14** is a combination of a polarizer **22** and a quarter-wave plate **24**, and the circular analyzer **16** is a combination of a quarter-wave plate **26** and an analyzer **28**. The circular analyzer **16** is arranged in a crossed Nicols fashion with respect to the circular polarizer **14**. A

crossed Nicols fashion refers to the arrangement of the polarizers such that their polarization axes are set 90 degrees from one another. In this method, monochromatic parallel beams emitted from the light source **18** are converted into circularly polarized light by the circular polarizer **22** and projected onto sample **12**. The light beams then pass through the circular analyzer **16** to be detected by the optical receiver **20**.

The birefringence of the sample may vary from location to location across the sample. Thus, in order to describe the birefringence of a sample, birefringence at a number of points along or distributed on the surface of the sample is measured. One procedure used in industry includes taking a measurement at one position on the cross section of a sample and then manually moving the sample e.g., by using a lab jack, so that the measurement is made at another test point on the cross section. The measurements are repeated at numerous test points about the cross section of the sample to generate a birefringence map. Because mapping requires a large number of points, mapping the sample manually is a difficult and time-consuming task. In some cases, the actual birefringence measurement is also performed manually, with the operator having to determine the actual angle of light extinction. Therefore, the accuracy of these measurements can vary from operator to operator.

SUMMARY OF THE INVENTION

The invention is a method for automating measurement of an optical property of a sample. The method comprises selecting a measurement aperture around a reference point on the sample, generating a set of grid nodes that fall within measurement aperture, calculating the radial distance of each node with respect to a reference point within the measurement aperture, and calculating the angular position of each node with respect to the vertical. The method further includes calculating the angular position of each node with respect to the vertical and moving a light source and a light detector along the vertical and rotating the sample to measurement positions within the measurement aperture. The calculated radial distances and angular positions are used to control positioning of the light source and the light detector and rotation of the sample. The optical property is measured at the measurement position by energizing the light source and interrogating the detector.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a prior art system for determining birefringence of a material.

FIG. 2 shows another prior art system for determining birefringence of a material.

FIG. 3 is a schematic of an automated system for measuring an optical property.

FIG. 4 is a block diagram of a process for measuring an optical property using the system shown in FIG. 3.

FIG. 5 shows how data points are sampled using the process described in FIG. 4.

FIG. 6 is a schematic illustration of a process used to generate nodes.

FIG. 7 shows the automated system of FIG. 3 at neutral position.

FIG. 8 shows data points sampled along orthogonal axes of a sample.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 3 illustrates an automated system **30** for measuring an optical property, e.g. birefringence, across a sample. The automated system **30** includes a light source unit **32** and a first polarizer **34**. The first polarizer **34** may be one made by Corning Inc., sold under the trade name Polarcor®. This type of polarizer creates linear polarized light and has a higher light extinction ratio ($<10^{-5}$) than commonly used sheet polarizers, which have extinction ratios of about 10^{-4}. However, the invention is not limited to this type of polarizer. Sheet polarizer or other types of polarizers, e.g., calcite polarizers, can also be used. The light source unit **32** and the first polarizer **34** are mounted on a vertically movable first translational stage **36**. The first translational stage **36** preferably has the ability to accurately move as little as 1 micron. Translational stages which can be used with the automated system **30** are commercially available and can be purchased, for example, from Newport Company (model # MTMCC1).

The automated system **30** further includes a detector end **42**. The detector end **42** comprises a quarter-wave plate **44**, a second polarizer or analyzer **46** oriented in a crossed Nicols fashion with respect to the first polarizer **34**, and a photomultiplier **48**. The second polarizer or analyzer **46** may be one made by Corning Inc., sold under the trade name Polarcor®, or may be other type of polarizer. The wave plate **44** is not

limited to quarter-wave plates, but may be a half-wave plate, for example. The detector end **42** is mounted on a second translational stage **50**. The second translational stage **50** can move simultaneously with the first translational stage **36**, while keeping the light source unit **32** and the detector end **42** optically aligned. The translational stages **36** and **50** may also move independently of one another along a selected line. The analyzer **46** is mounted in a rotation stage (not shown) which is also mounted on the second translational stage **50**. The rotation stage has the ability to rotate the analyzer **46** such that the angular position of light extinction can be measured.

The automated system **30** also includes a sample holder **40**. In the illustrated embodiment, the sample holder **40** is rotatable and comprises a series of plates with rings (not shown) for holding a sample of a selected shape, e.g., sample **38**. The sample holder **40** further comprises a controllable means (not shown) for rotating the sample **38**. Preferably, the sample holder **40** has the ability to rotate the sample **38** around a full circle. In the illustrated embodiment, the sample **38** is a birefringent lens blank which has parallel surfaces. It should be understood that the sample **38** can be any shape or material of a birefringent nature, as long as it can be placed physically in the sample holder **40** and can be rotated.

In operation, a light beam **54** from the light source unit **32** enters the polarizer **34**. The light beam in this embodiment is a He-Ne laser beam with a wavelength of 632.8 nanometers, but may be any other type of light beam. A planar polarized light **56** emerges from the first polarizer **34** and enters the sample **38**. Because of the birefringent nature of the sample **38**, when the planar polarized light **56** enters the sample **38**, it splits into two light rays (not shown). The two light rays (not shown) recombine into an elliptically polarized light **58** upon exiting from the sample **38**. The elliptical polarization of the light **58** is caused by the phase difference between the two light rays. The elliptically polarized light **58** then enters the quarter-wave plate **44**, where it is converted into a linearly or nearly linearly polarized ray **60**. This ray **60** enters the analyzer **46**, which is arranged in a crossed Nicols fashion with respect to the first polarizer **34**. The light beam emerging from the analyzer **46** then enters a photomultiplier **48**, which measures the light intensity.

The birefringence at a particular point in the sample **38** can be determined by measuring the angular position at which the light is extinguished as it passes through

the polarizers **34** and **46**. The angular position at which the light is extinguished is obtained by rotating the second polarizer or analyzer **46** with respect to the first linear polarizer **34** until the light intensity measured by the photomultiplier **48** diminishes to some minimum value or to zero. The measurements can be stored on an electromagnetic medium (not shown) and subsequently or simultaneously analyzed. Before measurements are taken, a computer **52** sends command signals to the translational stages **36** and **50** and sample holder **40** to align the point on the sample **38** with the light source unit **32** and the light detector end **42**. A series of data points can be taken along a vertical line through the sample **38** by moving the translation stages **36** and **50** vertically and measuring the angular position at which the light passing through the polarizers **34** and **46** is extinguished. Additional data points can be obtained by rotating the sample **38** through a predetermined angle and, thereafter, moving the translation stages **36** and **50** vertically to take measurements along a vertical line through the sample **38**.

FIG. 4 illustrates the process for automatically creating a birefringence map for a sample **61**. This process can be implemented using LabVIEW, a computer-based measurement and automation tool produced by National Instruments, or any other suitable data flow tool. The process starts with an input module **62** that prompts a user for information about the geometry of the sample **61**. The input module **62** would typically be a graphical user interface with one or more input boxes for receiving information from the user. By default, the input module **62** prompts the user for a length ***L*** of the sample **61**. The length ***L*** of the sample **61** depends on the shape of the sample. For a circularly-shaped sample, the length ***L*** is the diameter of the sample. For a quadrilateral sample, the length ***L*** is the smaller of the height and width of the sample. For other shapes, the length ***L*** can be the diameter of a circle that can be inscribed within the boundary of the sample. The input module **62** may also prompt the user for two lengths, e.g., height and width of the sample **61**, instead of one length or may accept a stream of data that defines the boundary of the sample.

In addition to prompting the user for information about the geometry of the sample **61**, the input module **62** prompts the user for the desired spacing ***S*** between data points on the birefringence map and for a number ***F*** that will be used to determine the fraction of the cross sectional area of the sample to be mapped. The number ***F*** would

have a value greater than 0 and less than or equal to 1. If the number ***F*** is 1, the entire cross section of the sample **61**, as specified by the geometric information supplied by the user, will be mapped. If the number ***F*** is less than 1, the boundary of the sample **61** and a portion of the sample **61** along the boundary will not be mapped. The portion of the sample **61** that will be mapped is measured in this embodiment from the geometric center of the sample. The input module **62** may also prompt the user for other parameters related to the measurement of birefringence, e.g., the thickness of the sample **61**. Because the process can be used to automatically measure optical properties other than birefringence, the input module **62** will generally be adapted to prompt the user for parameters related to the particular optical property being measured.

The process continues with a grid generation module **64**. FIG. 5 illustrates graphically the functions of the grid generation module **64**, which are to (1) determine the dimensions of a measurement aperture **68** of the sample and (2) create a grid **70** with nodes **72** that correspond to points within the measurement aperture **68** at which the optical property birefringence in this embodiment will be measured. The dimensions of the measurement aperture **68** are determined from the user-supplied geometric information for the sample **61**. Basically, the output of the grid generation module **64** is a matrix ***C*** and vectors ***R*** and ***Φ***. The matrix ***C*** contains coordinates of the nodes **72** in a Cartesian coordinate system that has its origin ***O*** coincident with the center of rotation of the sample **61**. In FIG. 5, the center of rotation of the sample **61** is assumed to be coincident with the geometric center of the sample **61**. The vector ***R*** contains radial distances of the coordinates ***C*** from the origin ***O***. The vector ***Φ*** contains the angles through which coordinates ***C*** must be rotated to become aligned with the Y-axis (vertical).

The operations of the grid generation module **64** are illustrated for the circular sample, e.g., a circular lens blank, shown in FIG. 5. However, the grid generation module **64** can be readily adapted to other non-circular shapes such as a quadrilateral. As illustrated in FIG. 6, the grid generation module **64** starts by multiplying the user-supplied length ***L*** of the sample **61** by the number ***F***, shown at **74**, to obtain the length ***X***. As previously discussed, the length ***L*** for a circular sample is the diameter of the sample. The length ***X*** corresponds to the diameter of the measurement aperture **68**

(shown in FIG. 5). The length X is divided by two, shown at **76**, and the integer quotient of the result is taken, shown at **78**, to obtain a length Y. The length Y corresponds to the radius of the measurement aperture **68**. It should be noted that the length Y may not be exactly equal to half of the length X because the integer quotient operation involves rounding off to whole numbers. The length Y is then divided by the user-supplied spacing S, shown at **80**, and the integer quotient of the result is taken, shown at **82**, to obtain the number Z of data points to be measured along the length Y.

Assuming that the length Y is superimposed on the positive X-axis of the coordinate system shown in FIG. 5, then the coordinates (x,y) of the Z data points or nodes along the positive X-axis would be:

$$(x,y) = \{(S,0), (2S,0), (3S,0),\ldots, ((Z-1)S,0)), (ZS,0)\} \qquad (1)$$

If the length Y is superimposed on the negative X-axis of the coordinate system, then the coordinates of the Z data points measured along the length Y would be:

$$(x,y) = \{(-ZS,0), (-(Z-1)S, \ldots, (-3S,0), (-2S,0), (-S,0)\} \qquad (2)$$

Taking into account the origin O of the coordinate system and the edges E_1 and E_2 of the measurement aperture **68**, the coordinates of the nodes **72** in the grid **70** can then be computed, shown at **84**, using the following expression:

$$(x,y) = \{(-X/2,y), (-ZS,y), (-(Z-1),y), \ldots,(-2S,y),(-S,y), (0,y), (-S,y), (-2S,y),\ldots, ((Z-1),y)\ (ZS,y), (X/2,y)\}$$

where

$$y = \{ -X/2, -ZS, -(Z-1)S,\ldots, -2S, -S, 0, S, 2S, \ldots, (Z-1)S, ZS, X/2\} \qquad (3)$$

The expression (3) will be evaluated for every value of y to obtain the coordinates of the nodes **72** in the grid **70**. The size of the grid **70** is (2Z+3) by (2Z+3). A non-square grid can be generated if two unequal lengths L_1 and L_2 are supplied to the input module **62**. In which case, two lengths Y_1 and Y_2 will be obtained using the process outlined above for length L, and the lengths Y_1 and Y_2 can be used to get the coordinates along the X-axis and the Y-axis, respectively.

The x- and y-components of the coordinates determined using expression (3) above are stored in the first column and second column of the matrix C, respectively. Note that the dimension of the matrix C will be (2Z+3) by 2. The matrix C represents

the points on the sample **61** at which birefringence or other optical property will be measured. The grid generation module **64** then computes the radial distance of each coordinate in the matrix ***C*** from the origin ***O*** of the coordinate system, shown at **84**, and determines if the radial distance falls within the measurement aperture **68**. Let ***Cx*** and ***Cy*** represent the data in the first column and second column of the matrix ***C***, respectively. Then the radial distance $\boldsymbol{R_i}$ of a coordinate $\boldsymbol{Cx_i, Cy_i}$, where i corresponds to a row in the matrix ***C***, can be determined as follows:

$$R_i = \sqrt{(Cx_i)^2 + (Cy_i)^2} \tag{4}$$

The radial distances $\boldsymbol{R_i}$ of all the coordinates $\boldsymbol{Cx_i, Cy_i}$ in the matrix ***C*** can be obtained by evaluating the expression (4) for all the rows in the matrix ***C***. The results are stored in the vector ***R***. The grid generation module **64** then evaluates the vector ***R*** to see if any of the radial distances $\boldsymbol{R_i}$ falls outside of the boundary of the measurement aperture **68**. For a circular measurement aperture **68**, this can be done simply by checking if $\boldsymbol{R_i}$ is greater than **X**/2. For non-circular shapes, there are several algorithms available for checking whether a point is within or outside of a boundary. Any radial distance $\boldsymbol{R_i}$ that falls outside of the measurement aperture **68** is removed from the vector ***R*** and the corresponding coordinate $\boldsymbol{Cx_i, Cy_i}$ is also removed from the matrix ***C***.

The grid generation module next determines the angular position $\boldsymbol{\Phi_i}$ of each coordinate $\boldsymbol{Cx_i, Cy_i}$ with respect to the positive Y-axis and stores the result in the vector $\boldsymbol{\Phi}$. The angular position Φ_i is given by:

$$\Phi_i = \tan^{-1}\left(\frac{Cx_i}{Cy_i}\right) \tag{5}$$

Note that Φ_i is zero when $\boldsymbol{Cx_i}$ and $\boldsymbol{Cy_i}$ are both equal to zero. If $\boldsymbol{Cy_i}$ is zero and $\boldsymbol{Cx_i}$ is positive or negative, then Φ_i is 90 or 270, respectively. The vector $\boldsymbol{\Phi}$ is sorted in ascending order, and the matrix ***C*** and vector ***R*** are also sorted so that each angular position $\boldsymbol{\Phi_i}$ corresponds to the correct coordinates $\boldsymbol{Cx_i, Cy_i}$ and radial distance $\boldsymbol{R_i}$. Assuming that the first entry $\boldsymbol{\Phi_0}$ in the vector $\boldsymbol{\Phi}$ corresponds to the angular position of the node **72** at the origin ***O***, then a vector $\Delta\Phi$ of incremental angular positions can be generated using the following expression:

$$\Delta\Phi_i = \Phi_i - \Phi_{i-1} \text{ where } i > 0 \tag{6}$$

The vector $\Delta\Phi$ may be used in place of the vector Φ to position align nodes with the Y-axis. The vector $\Delta\Phi$ can be sorted in ascending order. If vector $\Delta\Phi$ is used and sorted, any sorting applied to the vector $\Delta\Phi$ should also be applied to corresponding entries in the vector $\boldsymbol{R}$ and the matrix **C**. The vectors $\boldsymbol{R}$ and Φ (or $\Delta\Phi$) and the matrix $\boldsymbol{C}$ are stored on an electromagnetic medium **86** (shown in FIG. 4).

Referring back to FIG. 4, the process continues by moving the translation stages **36** and **50** and the sample holder **40** to the neutral position **88**, shown at **90**. FIG. 7 shows the neutral position **88** as a position where the polarizers **34** and **46** are aligned with center of rotation of the sample **61**. The process then continues by initializing the index $\boldsymbol{i}$ to 1, shown at **92**. The process then continues by starting the measurements. First, a check is performed to determine if $\boldsymbol{i}$ is less than or equal to $\boldsymbol{N}$, shown at **94**. $\boldsymbol{N}$ is the number of rows in the vector $\boldsymbol{R}$ or Φ or matrix $\boldsymbol{C}$ stored on the electromagnetic medium **86**. If $\boldsymbol{i}$ is less than $\boldsymbol{N}$, shown at **96**, the program reads the radial distance $\boldsymbol{R_i}$, i.e., the i^{th} entry in the vector $\boldsymbol{R}$, and the angular position Φ_i, i.e., the i^{th} entry in the vector Φ. If $\boldsymbol{i}$ is greater than $\boldsymbol{N}$, shown at **108**, the process is terminated.

As shown at **100**, the sample holder **40** (shown in FIG.s 3 and 7) is rotated by an angle Φ_i specified by the vector Φ so that the point to be measured is aligned with the vertical. For example, to make measurements at the node labeled C in FIG. 5, the sample **61** can be rotated through an angle Φ so that the node C is aligned with the Y-axis. This assumes that the sample **61** is initially at the neutral position. Alternatively, the program may use the incremental angle $\Delta\Phi_i$ to rotate the node C from its current position to the Y-axis. The vector $\boldsymbol{R_i}$ is used to determine how far along the vertical to move the translational stages **36** and **50** to take the measurements. The process may keep track of the current position of the translational stages **36** and **50** and move the translation stages **36** and **50** in increments or may return the translation stages **36** and **50** to the neutral position and move them in the number of units specified by $\boldsymbol{R_i}$. When the translational stages **36** and **50** and the sample **61** are at the appropriate height and orientation, respectively, the analyzer **46** is rotated to measure birefringence, as shown at **102**. The measurements made at **102** are stored in an electromagnetic medium **104**.

The next step is to increment $\boldsymbol{i}$ by one, shown at **106**, and repeat the steps **94** through **106** in the process until $\boldsymbol{i}$ becomes greater than $\boldsymbol{N}$, at which point the process is terminated. The measurements stored in the electromagnetic medium **104** can then be

accessed and analyzed, and the results of the process can be displayed, shown at **110**. Birefringence charts can be plotted as a function of the coordinates stored in the matrix ***C***. However, the user may choose to view the results in real time. In this case, the measurements are analyzed as they are obtained and the results are displayed. The process described above can be readily adapted to measure other optical properties, e.g., transmission. Any modification to the process shown in FIG. 4 will come in step **102**, which must be tailored to the desired optical property to be measured. As can be observed from the description above, the process provides an advantage in that a single operator can quickly and accurately create a birefringence map or other optical-property map of a sample.

It should be understood that in the process described above, the origin ***O*** of the coordinate system does not have to be at the geometric center of the sample **61**. The process will still work if the origin ***O*** is offset from the geometric center of the sample 61, but the origin ***O*** should remain within the measurement aperture **68** (shown in FIG. 5) of the sample **61**. The origin ***O*** would generally coincide with the center of rotation of the sample **61**. If the center of rotation is different from the geometric center of the sample, this information will be provided to the input module **62** and taken into account when generating the matrix ***C*** and the vectors ***R*** and ***Φ*** in the grid generation module **64**.

For birefringence measurements, it has been found that the sample holder **40** induces some localized stresses at the region where it supports the sample **61**. These localized stresses can affect the accuracy of the birefringence measurements. Therefore, measurements are preferably taken at the top half of the sample **61**, where the weight of the sample **61** is not bearing on the sample holder **40**. This means that even though the grid **70** is symmetrical about the center of rotation of the sample **61**, it may be better not to take advantage of the symmetry, but rotate the sample **61** through 360 degrees to take the measurements. The translation stages **36** and **50** would then be moved back and forth between the center and top edge of the sample **61**. By the time the sample is rotated through 360 degrees, measurements would have been made at all the appropriate points on the sample. For optical properties that are not sensitive to induced stresses, measurements can be made at both the upper and lower halves of the sample **61**.

The process can be adapted to make measurements only about orthogonal axes of the sample **61** only instead of mapping the entire sample **61**. In this case, as shown in FIG. 8, the grid **70** would simply be two orthogonal lines on the sample **61** with nodes **72** along the X-axis that are described by expressions:

$$(x,y) = \{(-X/2,0), (-ZS,0), (-(Z-1),0), \ldots,(-2S,0),(-S,0), (0,0), (-S,0), (-2S,0),\ldots, ((Z-1),0)\ (ZS,0), (X/2,0)\} \tag{6}$$

and nodes along the Y-axis that are described by expressions:

$$(x,y) = \{(0,-X/2), (0,-ZS), (0,-(Z-1)), \ldots,(0,-2S),(0,-S), (0,0), (0,-S), (0,-2S),\ldots, (0,(Z-1))\ (0,ZS), (0,X/2)\} \tag{7}$$

The measurements along the orthogonal lines would then be made using the same process illustrated in FIG. 4.

While the example embodiment described herein is directed to measurement of the birefringence of a sample, it should be clearly understood that the automated system can measure other types of optical properties, e.g., transmission. The process described above can easily be extended to other measurements, simply by changing some of the elements such as the analyzer or light source. It is also possible to perform continuous measurements while keeping spatial resolution constant. Also, the process can be extended to look at any property in which there is an energy source and a detector. Specifically, the process applies to any property that measures the state of the energy entering a sample and compares it to the state of the energy leaving a sample.

Those skilled in the art will appreciate that other embodiments of the invention can be devised which do not depart from the spirit of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

CLAIMS

What is claimed is:

1. A method for automating measurement of an optical property of a sample, comprising:

selecting a measurement aperture around a reference point on the sample;

generating a set of grid nodes that fall within the measurement aperture;

calculating the radial distance of each node with respect to the reference point;

calculating the angular position of each node with respect to vertical;

moving a light source and a light detector along the vertical and rotating the sample to measurement positions in which the light source and the light detector are aligned with one of the nodes in the measurement aperture, wherein the calculated radial distances and angular positions are used to control positioning of the light source and the light detector and rotation of the sample; and

measuring the optical property at the measurement position by energizing the light source and interrogating the detector.

2. The method of claim 1, wherein selecting a measurement aperture comprises obtaining information about the geometry of the sample.

3. The method of claim 2, wherein the information is a length of the sample.

4. The method of claim 1, wherein generating a set of grid nodes further comprises obtaining a desired spacing between the grid nodes

5. The method of claim 1, wherein the reference point is coincident with the geometric center of the sample.

6. The method of claim 1, wherein the reference point is coincident with a center of rotation of the sample.

7. The method of claim 1, further comprising discarding grid nodes having radial distances outside of the measurement aperture.

8. The method of claim 1, wherein the coordinates of the grid nodes, the radial distances of the nodes with respect to the reference point, and the angular positions of the nodes with respect to the vertical are stored on an electromagnetic medium, and wherein the tables are sorted such that the angular positions are in sequential order.

9. The method of claim 8, further comprising calculating incremental angular positions from the table of angular positions and storing the incremental angular positions in a table.

10. The method of claim 9, wherein the sample is rotated incrementally using the incremental angular positions.

11. The method of claim 1, wherein the optical property measured is birefringence and measurements are restricted to the upper portion of the sample as the sample is rotated to the measurement positions.

12. The method of claim 1, wherein the light source and the light detector are initially moved along the vertical such that the light source and the light detector are aligned with the reference point on the sample.

13. A computer readable storage medium containing an executable program for use in automating measurement of an optical property, the executable program comprising instructions that when executed by a computer enable the computer to:

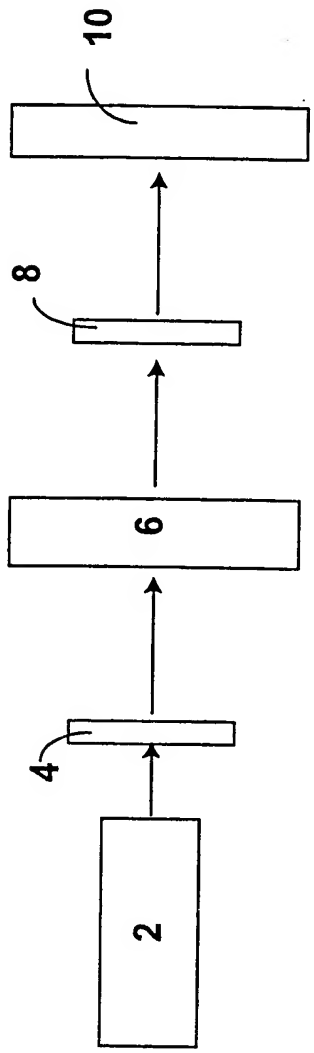
select a measurement aperture around a reference point on the sample;
generate a set of grid nodes that fall within the measurement aperture;
calculate the radial distance of each node with respect to the reference point;
calculate the angular position of each node with respect to the vertical;
generate signals to move a light source and a light detector along the vertical and to rotate the sample to measurement positions in which the light source and the light detector are aligned with one of the nodes in the measurement aperture, wherein the signals are generated in accordance with the calculated radial distances and angular positions; and
record measurements made at the measurement positions.

14. The program of claim 13, wherein the computer presents an input module that allows information about the geometry of the sample to be entered and selects the measurement aperture based on the information entered in the input module.

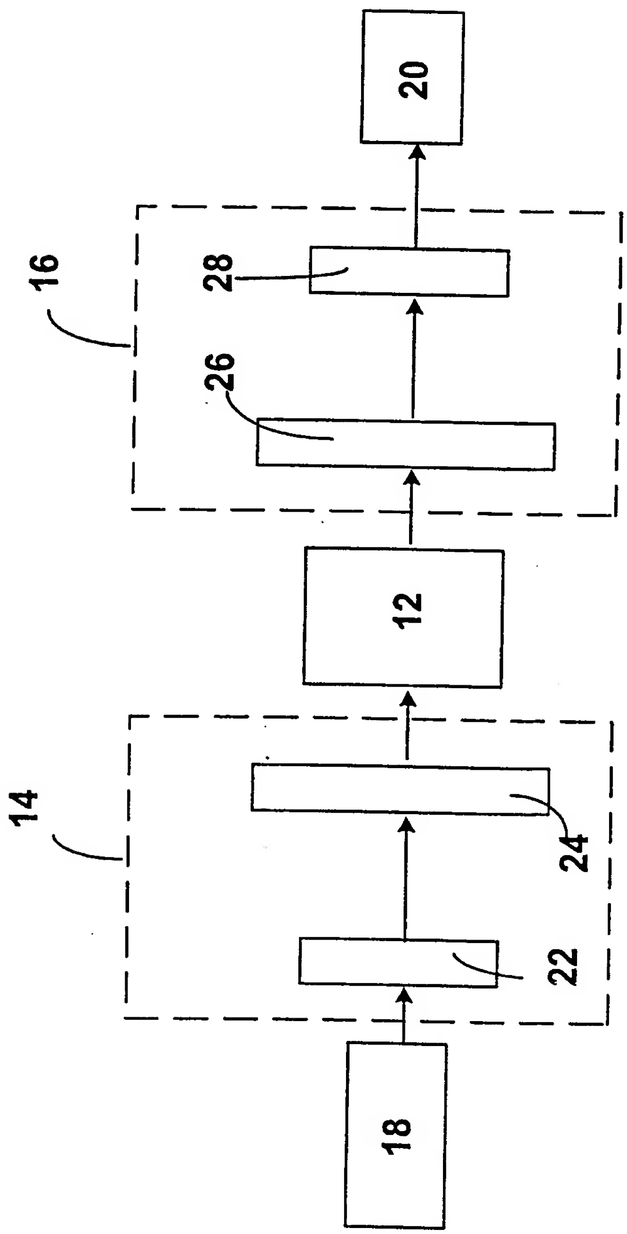
15. The program of claim 13, wherein the computer presents an input module that allows the desired spacing between the grid nodes to be entered.

16. The method of claim 14, wherein the computer discards the grid nodes having radial distances that fall outside of the measurement aperture.

17. The method of claim 13, wherein the computer analyzes the recorded measurements and displays the results.



(Prior Art)
FIG. 1



(Prior Art)
FIG. 2

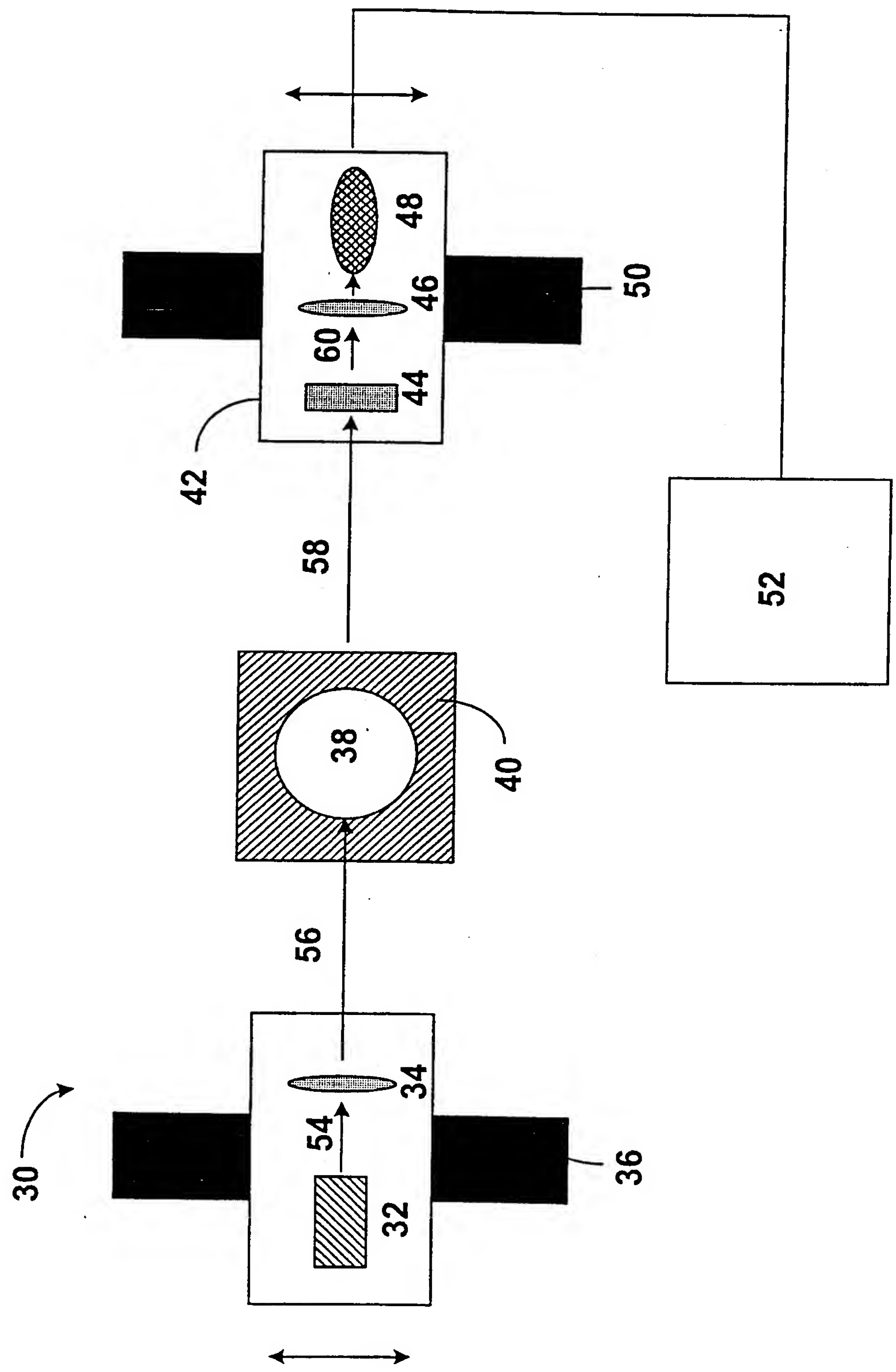


FIG. 3

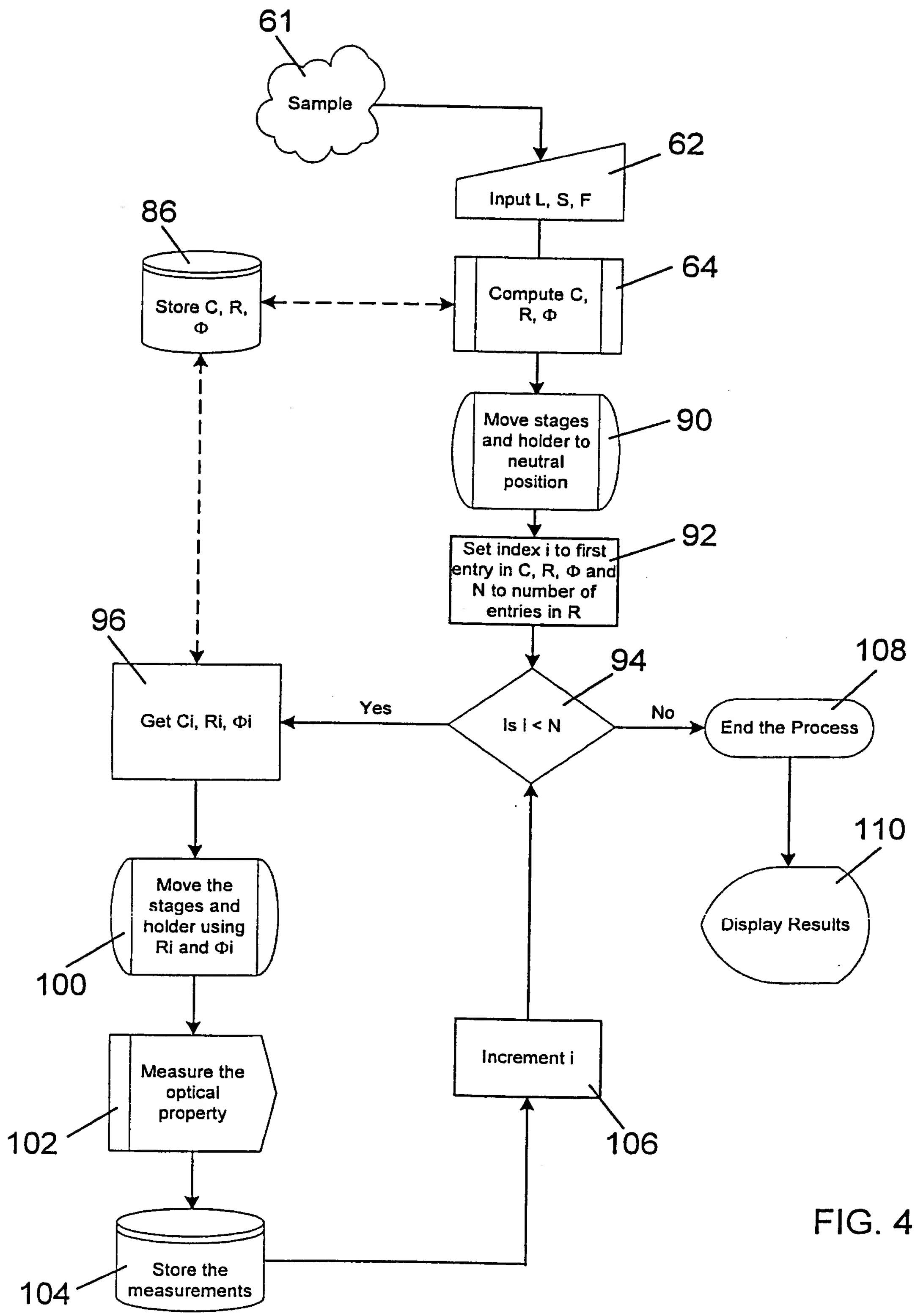

61
Sample
62
Input L, S, F
86
Store C, R, Φ
64
Compute C, R, Φ
90
Move stages and holder to neutral position
92
Set index i to first entry in C, R, Φ and N to number of entries in R
96
Get Ci, Ri, Φi
Yes
94
Is i < N
No
108
End the Process
110
Display Results
Move the stages and holder using Ri and Φi
100
Measure the optical property
102
Increment i
106
Store the measurements
104

FIG. 4

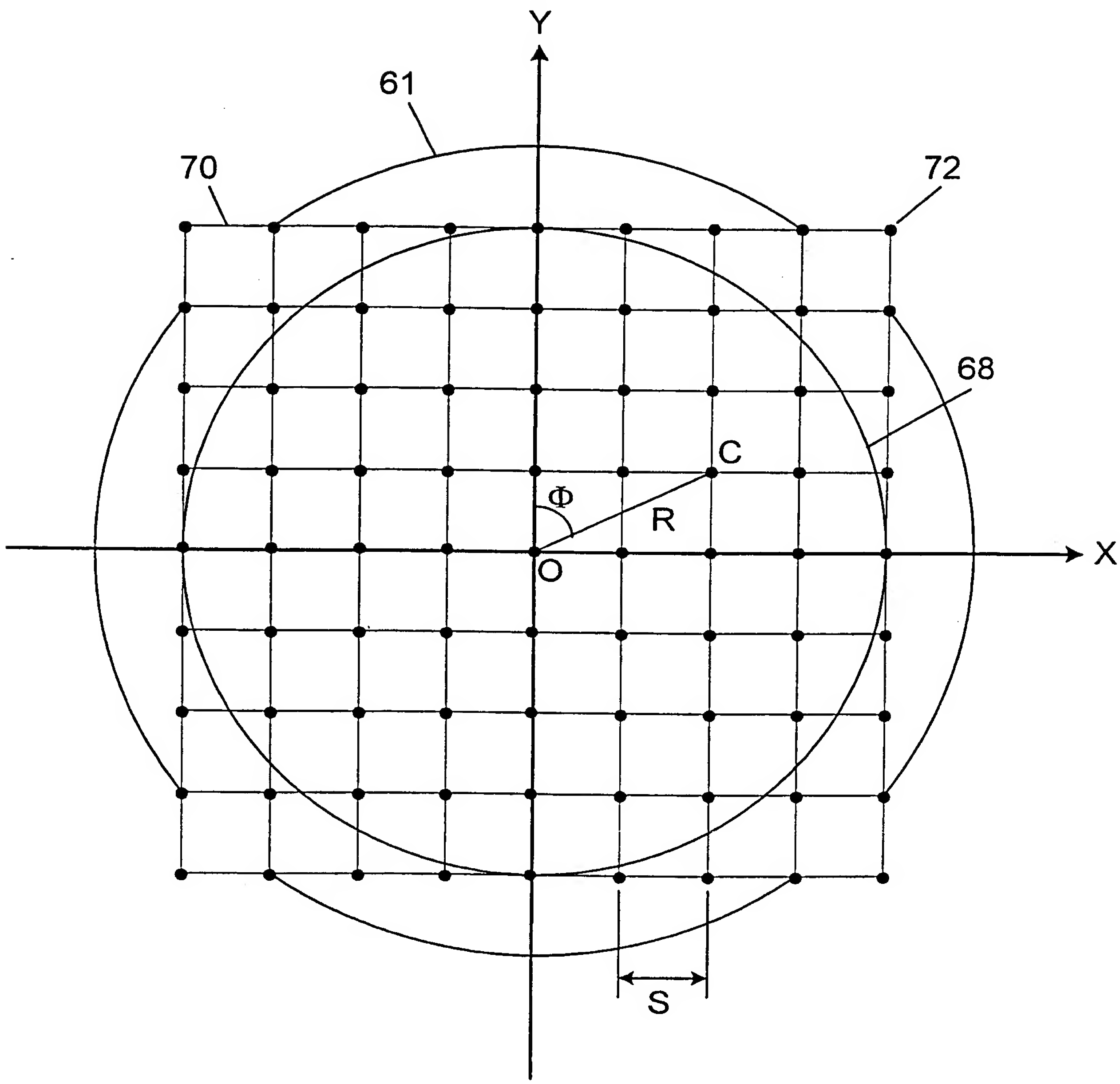


FIG. 5

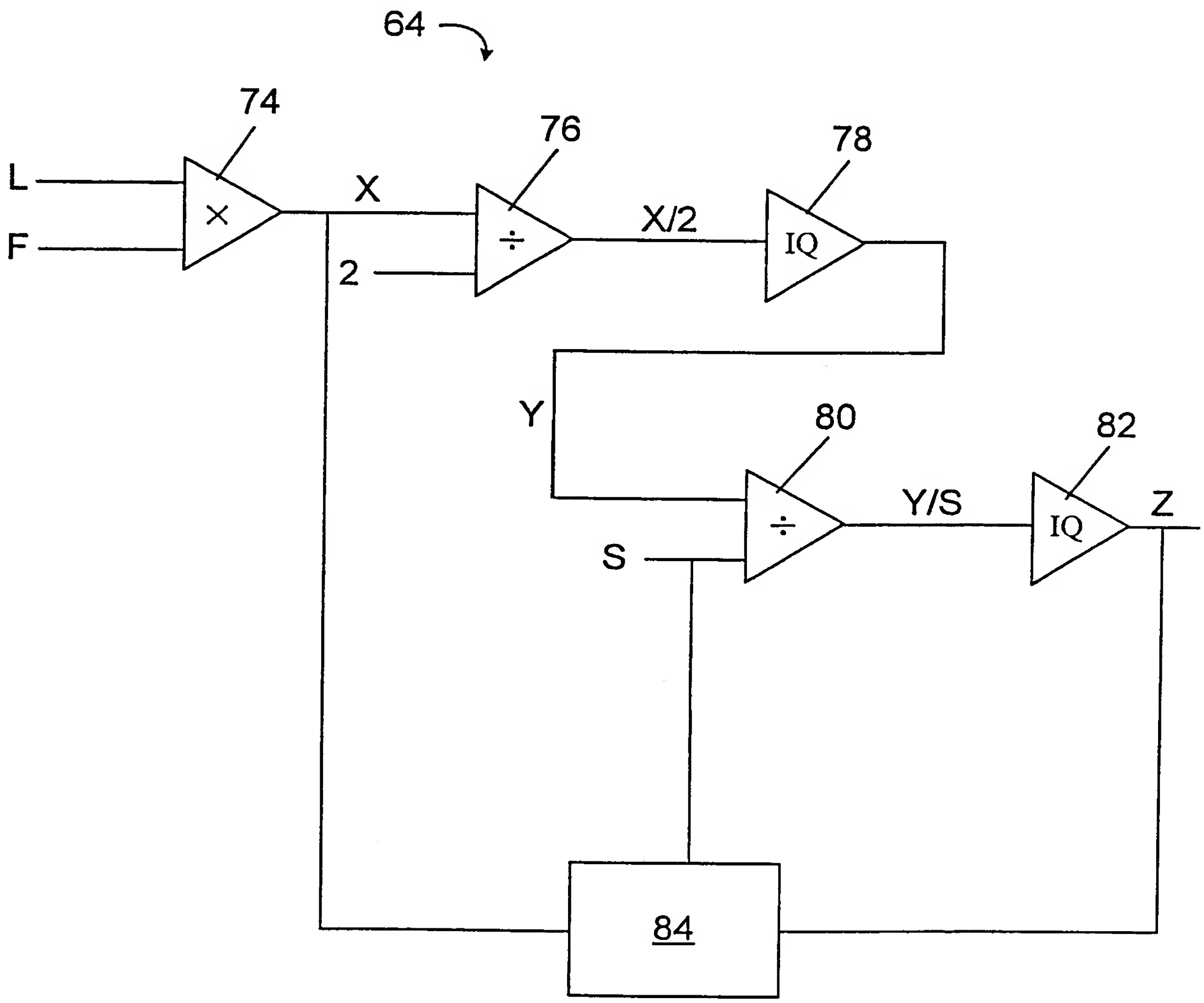


FIG. 6

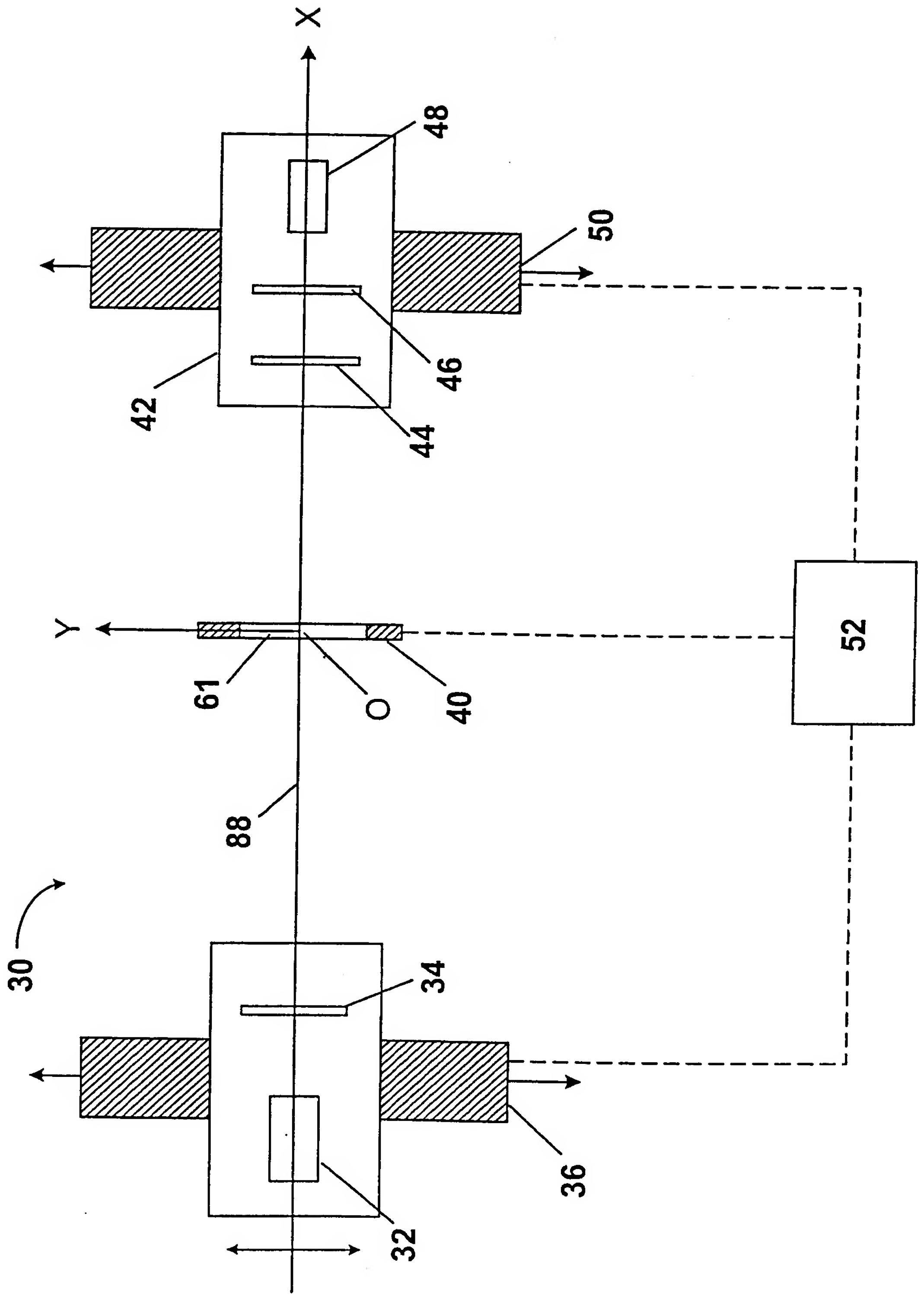


FIG. 7

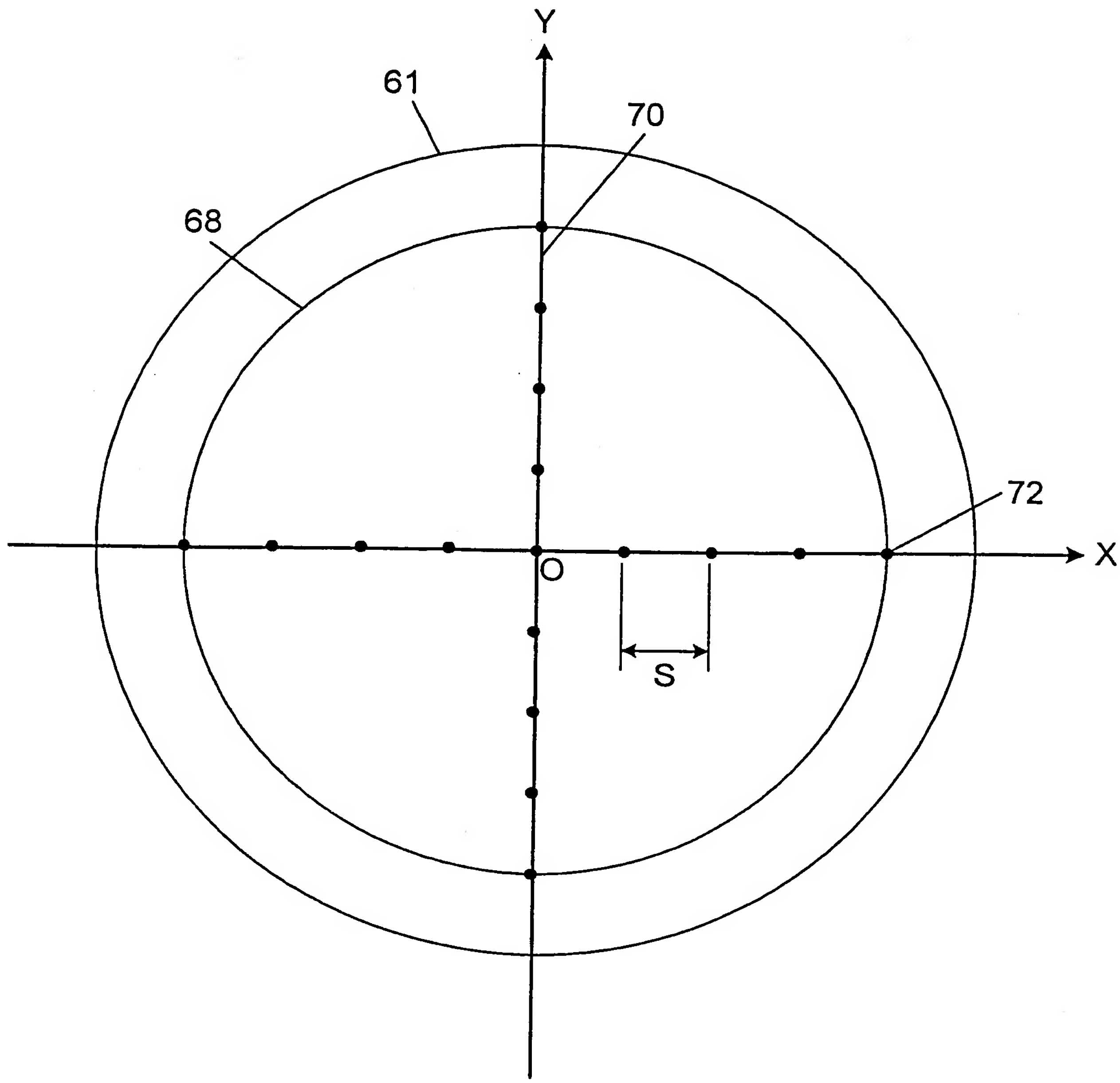


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/32768

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G01N 21/55, 21/47, 21/84; G01J 4/00
US CL :356/365, 364, 369, 426, 445, 446
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/365, 364, 369, 426, 445, 446

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS, EAST
search terms: birefringence, stage, rotating sample, moving detector, moving light source

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,811,775 A (ABU-SAUD) 21 May 1974 (21.05.1974), see entire document.	1-17
A	US 4,626,400 A (JOHNSON) 02 December 1986 (02.12.1986), see entire document.	1-17
A	US 5,028,774 A (YOSHIZAWA et al) 02 July 1991 (02.07.1991), see entire document.	1-17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 FEBRUARY 2001	26 FEB 2001

Name and mailing address of the ISA/US	Authorized officer
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